CERTIFICATION OF THE ROUGHNESS MEASURING INSTRUMENT

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ABSTRACT

Deterioration in the roughness of pavement is generally due to traffic and environmental loads as the period of public use increases. Since the roughness of pavement is directly related to driving comfort, a road maintainer is necessary to provide a satisfactory level in the roughness of the pavement. This in turn requires an objective evaluation for new pavement and for pavement in service. Modern Korean road projects use either a 7.6m long profilometer as specified in KS F 2373 or an automatic measuring instrument. However, there is no way to achieve objective verification of the automatic measuring instrument prior to the roughness evaluation. Verification of the measuring instrument is necessary to prove the objectivity of the instrument.

This study suggests an alternative method for certifying the roughness measuring instrument to more effectively use the automatic measuring instrument. This certification method uses the verification of the relationship between leveling and ROMDAS Z250. It then uses the verification of the relationship between ROMDAS Z250 and the automatic measuring instrument. The International Roughness Index (IRI) was used for this study because it is a roughness index that is accepted globally.

1. INTRODUCTION

Deterioration in the roughness of pavement such as cracking and plastic deformation is generally attributable to traffic and environmental loads. Roughness deterioration is accelerated as the period of public use increases. Pavement roughness is defined by a driver’s perceived sense of comfort on the road. Therefore roughness is considered an important performance factor for roads.

The roughness of pavement is directly related to driving comfort, so it is important for a road maintainer to maintain and provide for a satisfactory level in the roughness of pavement to the drivers. Modern Korean road projects use either a 7.6m long profilometer specified in KS F 2373 or an automatic measuring instrument. The method specified in KS F 2373 is useful for new pavement projects, but it is inconvenient to apply to roads in service since it requires more time and is more difficult to apply than other methods. The automatic measuring instrument, for instance, is useful in both new pavement and in roads in service because of its short measuring time. For this reason, the automatic measuring instrument is most widely used in Korea. However, there is no objective verification of the automatic measuring instrument prior to the roughness evaluation. Therefore, a verification of the measuring instrument is necessary to prove its objectivity.

This study suggests a method for objectively certifying the roughness measuring instrument to more effectively use the automatic measuring instrument. This method requires that the certification of

the instrument be carried out as follows [1]:

(1) Conduct field test using the targeted instrument and the reference instrument

(2) Distance Measuring Instrument (DMI) analysis based on the field test results

(3) Analysis of error tolerance of the targeted instrument compared to the reference instrument and the repetitiveness of each instrument.

The most precise reference instrument is the rod and level [2]. Instruments that use a slope profiler include: the dipstick, the rolling dipstick, ROMDAS Z250, SurPro 1000, ARRB Walking Profiler, and IRIS [3]. The certification method operates by using the verification of the relationship between leveling and ROMDAS Z250. It then uses the verification of the relationship between ROMDAS Z250 and the automatic measuring instrument. The International Roughness Index (IRI) is used for the roughness index since it is an internationally accepted measure.

2. ROUGHNESS

The roughness of pavement is an important factor because it is directly related to driving comfort. Because of this, a road maintainer is necessary to provide a satisfactory level in the roughness of the pavement.

2.1 *Definition of Roughness*

Roughness is defined by the sense of comfort perceived by a driver on the road. The following includes various indices of roughness [3]:

(1) International Roughness Index (IRI)[1]
(2) Ride Number (RN)
(3) Ride Quality Index (RQI)
(4) Truck Ride Number (TRN)
(5) Profilograph Index (PrI)

2.2 *IRI Calculation*

The IRI is calculated from a quarter-car simulation as follows:

① Data Input (raw data)

② Moving average filter : filtering to apply to a 1/4 car model (250mm sample interval)

③ Quarter-car simulation at driving speed of 80km/h (Fig. 1) : sums up absolute displacement (difference) between sprung mass (Euler's integral) and unsprung mass (Taylor series)

④ Accumulator : accumulated displacement (difference)

⑤ IRI calculation

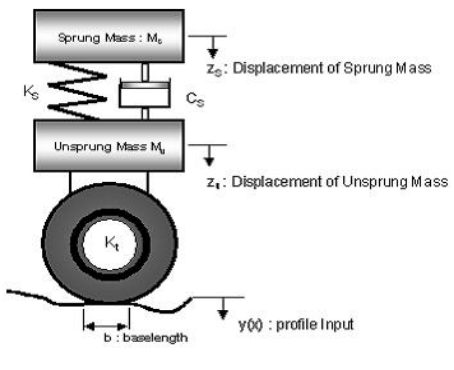

Figure 1. Quarter-car simulation [4, 5]

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[1] The IRI is an officially accepted method that is used throughout the world.

2.3 *Roughness Measurement*

The roughness measurement includes:

1. Leveling with rod and level-measuring road surface directly (Fig. 2),
2. ROMDAS and dipstick-using slope profiler (Fig. 3), and
3. Automatic measuring instrument such as ARAN, K.J., Law, KRISS, etc.-widely used on the roads in service (Fig. 4).

Frequently, measuring instruments such as the rod and level, ROMDAS, and the dipstick are used to calibrate/verify automatic measuring instruments. Since automatic measuring instruments can measure the roughness of pavement under normal traffic conditions (i.e., speed, flow), they allow for the field tests to be conducted quickly and without disruption to traffic.

Figure **2**. Rod and level

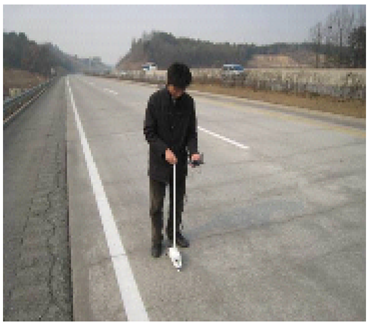

Figure **3**. ROMDAS

Figure **4**. ARAN

2.4 *Certification of automatic measuring instrument*

To certify an automatic measuring instrument, a reference instrument is required. In this study, ROMDAS Z250 was chosen as a reference instrument. Leveling with the rod and level was carried out for verification purpose. The results of the automatic measuring instrument were verified after being compared with the verified ROMDAS results. The verification procedure is as follows (Fig. 5):

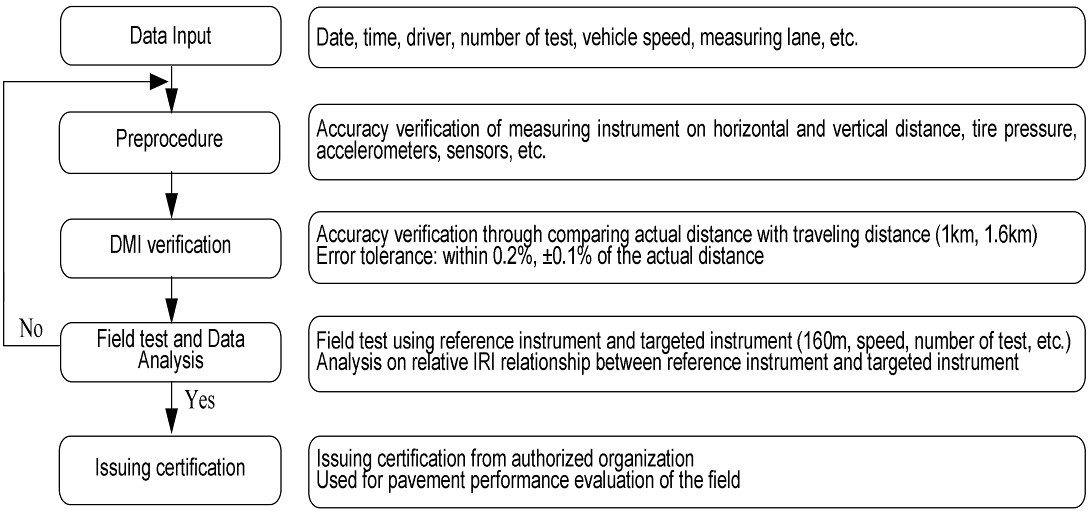

Figure 5. Flowchart for equipment certification

3. FIELD TEST

Overall two field tests were conducted: a test to verify the reference instrument and a test to verify the automatic measuring instrument. The test of the reference instrument included lab tests and field tests. The test of the automatic measuring instrument used procedures recommended in engineering literature.

3.1 *Verification of reference instrument*

A lab test and a field test were conducted on the reference instrument. Leveling was carried out at the same time. The test distance included a short section (1.5 meter) for the lab test and a long section (30 meter) for the field test.

(1) Lab Test

ROMDAS, a type of reference instrument similar to a dipstick, uses an equivalent measuring method to the dipstick. For the purpose of verifying the instrument, a profile was set at 1.5 meters. The profile was measured by leveling and by ROMDAS. An analysis of the lab test results show the R^2 value is 0.9972 and that the profiles measured by the two different instruments were very similar to each other (Fig. 6).

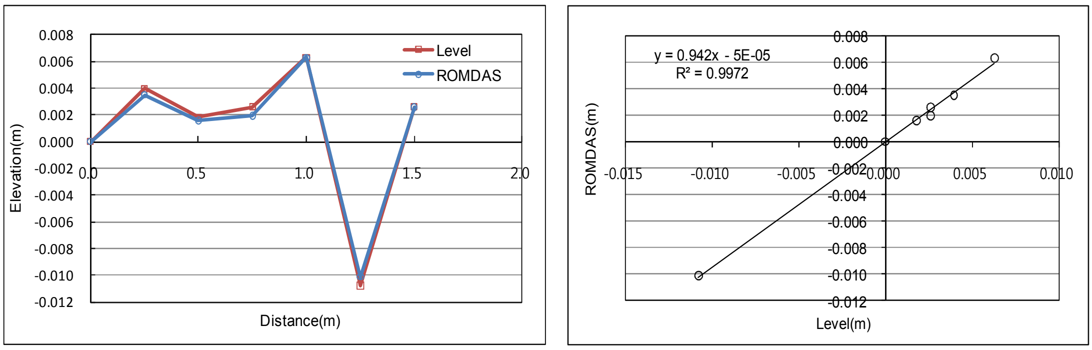

Figure 6. Results of reference instrument verification (Lab test)

(2) Field Test

Based on the verification results of the first lab test, a second test was performed at the field (Fig. 7). Field tests measured by a rod and level and by ROMDAS were performed in the 30 meter section. Leveling used a 50cm ruler attached to the rod for a more accurate measurement and investigation.


Figure 7. Field test

The deviation between leveling and ROMDAS at each measuring point was less than 1 mm (Fig. 8). From Figure 8, ROMDAS had a higher deviation than leveling because the ROMDAS is measured by eye, making it very difficult to match the levels of the two instruments. The R^2 value was 0.86 which is a good correlation between leveling and ROMDAS (Fig. 9).

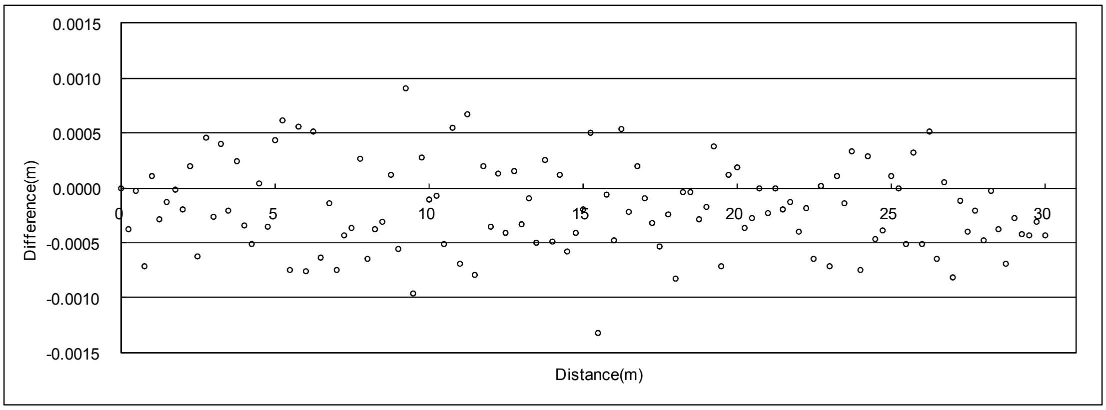

Figure 8. Difference between Level and ROMDAS (Field test)

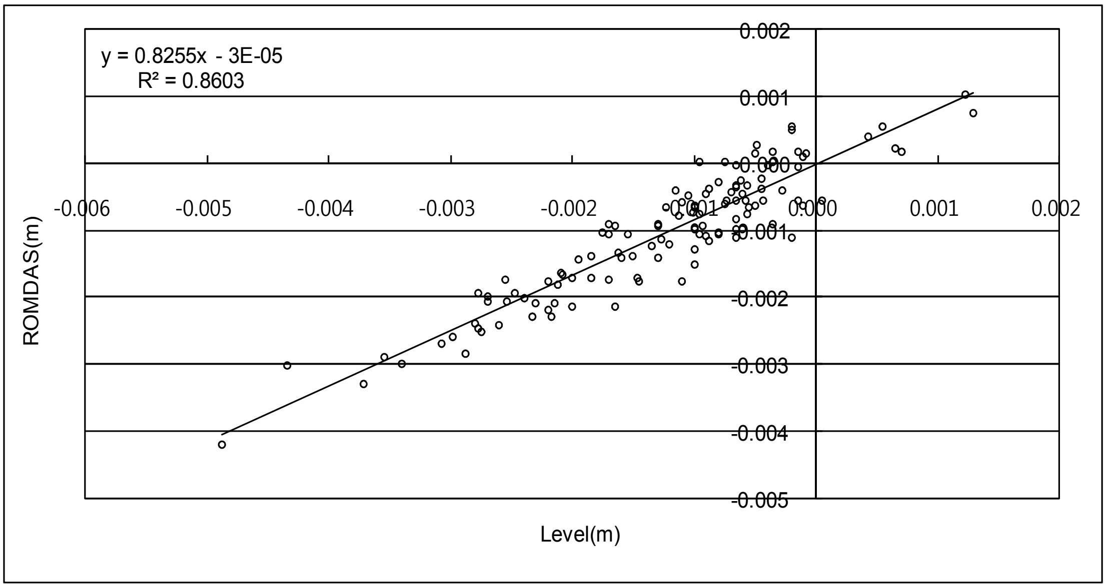

Figure 9. Correlation between Level and ROMDAS (Field test)

3.2 <u>*Field Test by the automatic measuring instrument*</u>

The field test by the automatic measuring instrument was conducted on the test road located at the central interstate highway. Four instruments were tested and the test items were chosen to verify the DMI and the IRI.

(1) DMI Verification

The distance is measured by rolling a hoop in the DMI verification section, but the result did not match the actual distance. Instead, the 1 km section was measured using metal measuring tape. For this section, five separate tests were carried out for each of the four instruments.

(2) Verification of the reference instrument

Two ROMDAS instruments were used as reference instruments. The distance was measured simultaneously in 200 m long sections of good roughness condition. These instruments were provided

by a private company and a verifying organization to see that the measurements were similar to each other.

(3) Verification of automatic measuring instrument

For the purpose of verifying the IRI, field tests were performed in different sections. These sections included: (i) an acceleration/deceleration section, (ii) a good/bad roughness condition section, and (iii) a transition section (as shown in Fig. 10). To see whether the instruments yield consistent measurements, the field tests were performed on the good roughness condition section and the bad roughness condition section. Ten repetitive tests were performed at three different measuring speeds—at 40 km/h, 60 km/h, and 80 km/h.

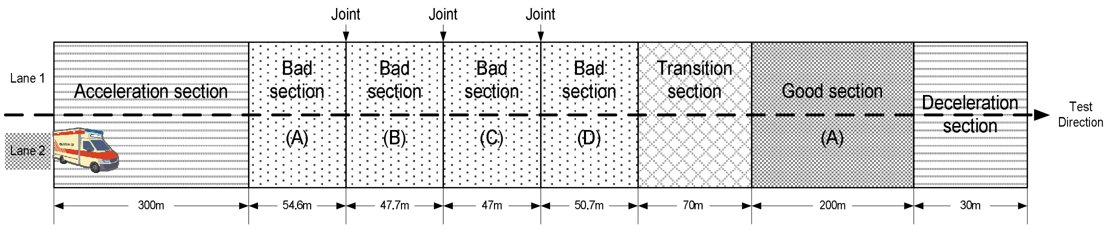

Figure 10. Test section for IRI verification

4. RESULTS OF FIELD TESTS

4.1 *Results of verification for the reference instrument*

From the Figure 11, the test results for the reference instruments over the 200 meter section yielded similar pavement profiles: the two IRI results were 1.99 m/km and 2.04 m/km. This study uses the average value of these two instruments, 2.02 m/km, to verify the automatic measuring instrument.

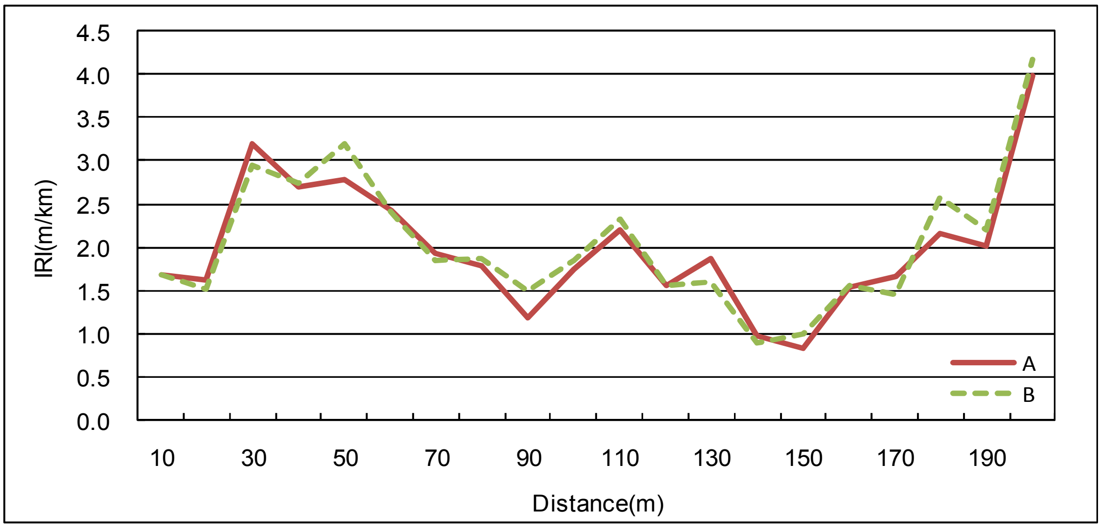

Figure 11. Comparison of reference instruments

4.2 *Results of verification for DMI*

The Distance Measuring Instrument (DMI) was verified based on repetitive measurements of each targeted instrument over a 1 km section. Table 1 gives the test results. Instruments A, B, and C show similar results of the DMI. The difference is less than 0.1% of deviations. However, instrument D

shows a 0.8% deviation. The acceptable tolerance range is 0.1~0.2%. Therefore the deviations of instrument A, B, and C are within this range and valid, but instrument D needs another test for verification.

Table 1. Results of DMI verification

Number of test	1	2	3	4	5	Average
A(m)	1000	1000	1000	1000	1000	1000
B(m)	1000	1000	1000	1000	1000	1000
C(m)	1000	1000	1000	1000	1000	1000
D(m)	992	993	992	993	992	992

4.3 *Results of verification for the automatic measuring instrument*

The verification for each of the automatic measuring instruments was performed based on the results from the verification of the reference instrument (see section 4.1). Five results from the ten measurements were selected for the analysis. The best fit profile was chosen which had a similar IRI value to the reference instrument. Figures 12 through 14 show the profile for each of the four instruments and the reference instrument at the different speeds. As the figures show, instruments A, B, and C show consistent results with the reference instrument. However, instrument D shows dissimilar results to the reference instrument and this deviation is especially high for measuring speeds under 40 km/h.

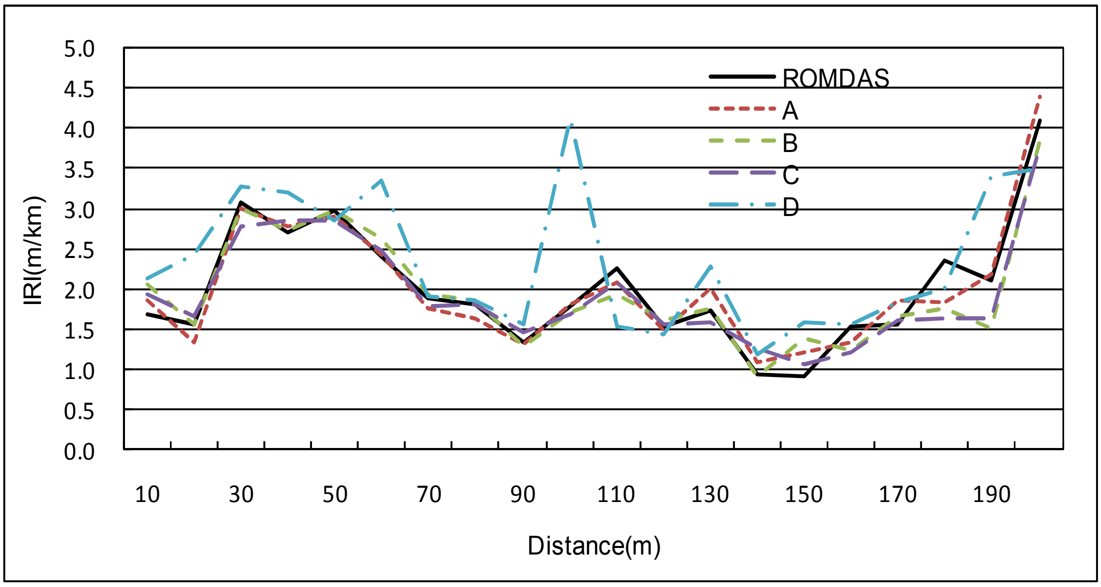

Figure 12. Results of IRI field test (40km/h)

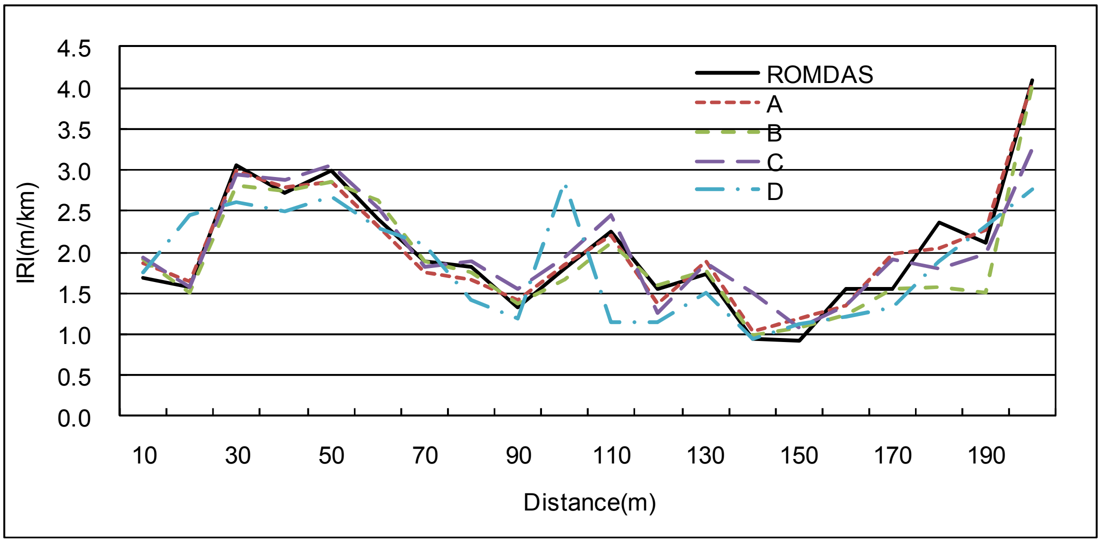

Figure 13. Results of IRI field test (60km/h)

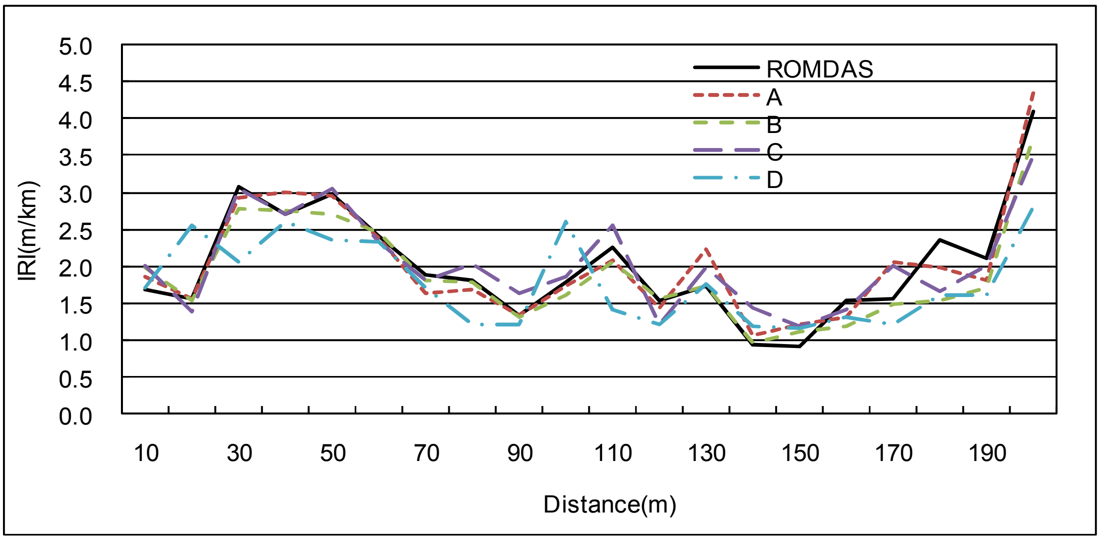

Figure 14. Results of IRI field test (80km/h)

Standard value and tolerance are levels that are needed for the purpose of verification. For the standard value, the value of the reference instrument was chosen. For the tolerance, the M/n road value and Japanese code value were chosen (Table 2).

Table 2. Standard Value and tolerance

Standard Value (ROMDAS)	M/n road	Japan
2.02	- IRI (m/km) : ±5% (1.92~2.12) - Standard Deviation (SD) / Average ∗100 : under 3.	- IRI (m/km) : ±30% (1.41~2.62)

Generally, the analysis of the IRI values consists of a comparison of:
(i) the IRI results between the reference instrument and the targeted instrument, and
(ii) a repetitiveness analysis of the targeted instrument.

This study draws its conclusions after analyzing the IRI results. The repetitiveness analysis of the targeted instrument will be carried out later. Table 3 represents the analysis results of each targeted instrument based on the best fit of the five profiles. Instruments A and C show very similar results to the standard values, whereas instruments B and D need modification or a complementary test.

Table 3. Results of IRI verification

Number of Test	IRI(m/km)-A			IRI(m/km)-B			IRI(m/km)-C			IRI(m/km)-D		
	40	60	80	40	60	80	40	60	80	40	60	80
1	1.99	2.00	2.04	2.05	1.86	1.85	1.94	2.04	2.02	2.20	1.89	1.59
2	2.04	2.08	2.03	2.00	1.96	1.95	1.99	2.02	2.05	2.24	1.99	1.74
3	2.02	2.06	2.04	1.91	1.88	1.91	2.09	2.00	2.05	2.44	1.81	1.85
4	2.04	2.00	2.03	1.93	1.91	1.88	1.93	2.00	2.04	2.39	1.89	1.96
5	2.01	1.98	2.00	1.95	2.04	1.86	1.98	2.04	2.00	2.50	1.70	1.79
Average(A)	2.02	2.02	2.03	1.97	1.93	1.89	1.99	2.02	2.03	2.36	1.86	1.78
Standard Deviation(B)	0.021	0.044	0.017	0.059	0.07	0.043	0.063	0.02	0.019	0.129	0.107	0.136
B/A∗100	1.03	2.16	0.86	3.00	3.65	2.25	3.16	1.00	0.93	5.48	5.77	7.64

Table 4 summarizes all the test results. Three instruments passed the DMI tests and one instrument needs a complementary test. As for the IRI, instrument A passed all tests regardless of the measuring speed. Instrument B passed the test where the measuring speed was 40km/h, but did not pass the tests at 60 m/h and 80 km/h. Instrument C passed all tests at 60km/h and over. Instrument D failed all of the IRI tests and the DMI test.

Table 4. Results of automatic measuring instrument verification

Verification Item		Instrument A -speed(km/h)			Instrument B -speed(km/h)			Instrument C -speed(km/h)			Instrument D -speed(km/h)		
		40	60	80	40	60	80	40	60	80	40	60	80
IRI	M/n	P	P	P	P	P	F	P	P	P	F	F	F
	Japan	P	P	P	P	P	P	P	P	P	P	P	P
B/A∗100		P	P	P	P	F	P	F	P	P	F	F	F
DMI		P			P			P			F		

P : Pass, F : Fail

5. CONCLUSIONS

An automatic measuring instrument is required to evaluate the pavement condition of roads in service in a fast and effective way. Many studies of objective verification and certification of the automatic measuring instrument are in active progress these days. After researching existing literature,

this study employed the most applicable methods in an attempt to verify the automatic measuring instruments objectively. Lab tests and field tests were performed for the reference instrument, ROMDAS Z250, and the automatic measuring instrument. Based on these test results, an analysis of each instrument was carried out for the certification purpose. The International Roughness Index (IRI) was chosen for the purposes of this study.

The conclusions that can be drawn from this study are as follows:

(1) For the purpose of verifying the roughness measuring instrument objectively, verifications of the reference instrument, DMI, and IRI need to be carried out.

(2) Verification of the reference instrument is performed by leveling in the lab and field. The results of both instruments were very close to each other and the deviation was less than 1 mm. As a result, ROMDAS Z250 is suitable as a reference instrument.

(3) Two reference instruments (ROMDAS) and four roughness measuring instruments were tested at the field and the results were analyzed. Ten repetitive tests were conducted at different measuring speeds and the analysis was performed in terms of DMI and IRI values.

(4) From these results, the two reference instruments yielded similar results. Among the four instruments, two of them had no problems with the issuing of certification and one of them needed partial modification or a complementary test. The last instrument needed an entire modification or a complementary test.

(5) Also from these test results, when the certification is issued on the automatic measuring instrument, the verification standards of each factor are recommended as follows: (i) ±0.1% of the actual distance in DMI, (ii) ±5% of the reference IRI, (iii) the standard deviation/IRI average of the profile should be less than 3, and (iv) the measuring speed should stay within 60km/h~80km/h.

(6) Cross-correlation analysis to verify repetitiveness of the instrument is in progress.

Based on the results of this study and from the introduction of a certification system for the roughness measuring instrument, more objective evaluation on the pavement can and will be conducted and the certification of the instrument will be performed frequently.

ACKNOWLEDGEMENT

This research paper is based on the Standardization Project of Construction Criteria provided by Performance in Regard to Construction and Transportation R&D, Policies and Infrastructure ('06~'11).

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